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Nano-fertilizers and their role in plant nutrient management

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Abstract:

The conventional fertilization system is now not suitable in the present agriculture system due to limited resources and low use efficiency, and costly fertilizers and other environmental associated factors. The development of improvised fertilizers using nanotechnology is the most potential approach, which includes development and improvisation of nanofertilizers. Nanofertilizers utilizing in crop fertilization process increases crop production substantially. Nanofertilizers acquire some characteristic features which contribute to develop of precision base agricultural. Application of nanofertilizers cause increased efficacy of the micro and macro elements made available to plants growth and development. The use of nanofertilizers offers a several benefits over conventional fertilizer in present agriculture system, importantly nanofertilizers exhibit slow and regulated release of nutrients into the soil leading to nutrients effective availability. Nanofertilizers help to optimize nutrient management and facilitate higher nutrient use efficiency at various developmental stages in plants, causing more yields in contrast of traditional chemical fertilizers. The advances of nanobiotechnology offer several opportunities in agriculture system for optimum utilization of resources, nutrient management and crop production. The value addition in nutrient content and quality in food crops is another area that is least explored, the potential role of nanofertilizers in augmenting food nutrient value through nutrient fortification in several crops are suggested by various studies. In the recent years, various reports suggested the potential benefits of nanofertilizers in precise agriculture system that supports the increased nutrient uptake, soil nutrient enhancement, improved food nutrient quality, minimize nutrient loss, and also reduces the soil toxicity because of the heavy application of the traditional fertilizers in present agriculture system.

Key words*:* Nano-Fertilizers, nutrient use efficiency, crop production, nutrient biofortification, sustainable agriculture

INTRODUCTION

The present agriculture scenario needs most concern to enhance agriculture production to cater increasing food requirement to feed the growing global population. It is also very much important to develop different technologies and strategies in the present agriculture system to boost crop

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productivity and support agriculture sustainability. In the last decade, nanotechnology has emerged as promising technology in this sector to cater effective agricultural crops management and boost crop production. The crop nutrient management is one of the area, that needs to be extensively explored, and nanotechnology could provide plausible solution in this direction. Crop fertilization is very crucial practice in agriculture system required for more crop and better yield; therefore, it is important to look for suitable technologically evolved approaches in the agriculture system for the fertilization process for easy bioavailability of nutrient to the crops. This will increase the crop yield in an eco-friendly manner [1]. The present agriculture system is heavily using synthetic agrochemicals which include pesticides, herbicides and synthetic fertilizers. Such agrochemicals are used in agriculture for crop protection and to improve crop growth and production. As per the recent report of FAO, the global production of synthetic fertilizers was about 118.2 Mt in 2019 [2], and is expected to continuously rise in future also to cater for the growing need of food demand by 9.6 billion people globally by 2050, awhich is a big challenge to the scientists. [3]. However, the current agricultural practices in the agricultural system are not sufficient enough to use the fertilizers in their actual capacity, and also are not able to give sufficient thrust to enhance NUE, and uptake and bioavailability of nutrients to the plants, resulting in low crop production less utilization of resources [4]. There are studies on the nutrients used by plants revealed that conventional chemical fertilizers are hardly utilized to their maximum potential in exiting the agriculture system. Most of the important nutrients (including both macro and micro) available in the fertilizers are underutilized due to less NUE and wastage through diverse means including leaching, degradation, immobilization, hydrolysis etc. For example, some of the important nutrients like, Nitrogen, Phosphorous and Potassium are hardly used by the plant to as low as 30–35%, 18–20%, and 35–40%, respectively [5].

The prolonged use of chemical fertilizers in traditional agriculture system extensively to improve nutrient content in soil and also soil fertility has started showing adverse impact and reduced soil fertility along with water quality. Conventional nitrogen fertilizers due to their less availability to plants cause an adverse impact on the environment triggering eutrophication of water bodies, increasing soil acidity and loss of soil biodiversity [6] [7].

In recent years, the focus is shifted on nanotechnology in the agriculture sector to explore new technology development and innovative approaches to boost agricultural sustainability. Nanotechnology offers potential approaches towards agricultural sustainability through several ways including effective use of agrochemicals, increasing efficiency and minimizing the loss of resources. The nano-materials are proved to be an important carrier for agrochemicals and facilitate nutrients supply to plants through regulated manner and witnessed enhanced nutrient use efficiency that translated into more crop production [8, 9]. The development of nanofertilizers for contemporary agriculture system can provide a potential boost to agronomic sustainability through diverse

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approaches i.e, slow delivery of nutrients in a controlled way, and more effective nutrients bioavailability, enhanced nutrient uptake and NUE, further, it is corroborated with resource conservation, reduced nutrient leaching and nutrients loss in environment etc. nutrients loaded nanofertilizers, offer sustained and slow nutrients delivery so that it can be made available to plants for better utilization under normal conditions. Nanotechnology offers huge potential to give a boost to crop production and promote food security in many ways including crop fertilization, which is the most promising practices to enhance crop productivity. The huge and indiscriminate application conventional Nitrogen fertilizers for agriculture purpose put additional burden on the environment adversely by contributing in the accumulation of atmospheric N_2O, which is one among the different greenhouse gases [10]. The nutrient use efficiency in the present agriculture system is still very low. Despite several efforts, more than 50% nitrogen used in agriculture for crop fertilization lost and contribute to the environmental problem [11, 10].

According to EPA 2017, agricultural practices also contribute to emit around 10% greenhouse gases of all greenhouse gas emission; therefore, taking into the fact count there should be much concern in this regard to reduce the environmental impact [12].

Nonmaterial based fertilizers are more effective as compared to conventional synthetic fertilizers, due to their high surface area to volume ratio, letting them increase nutrient use efficiency and low quantity of application, leading to reduce loss of fertilizers released into the environment [13]. Nanofertilizers loaded nutrients can be uptake by root through different routes and means, which includes, ionic channels, aqua-porins, through transport proteins, and by endocytosis etc. [14].

Agriculture is the principal source of food to cater to the nutritional need of the population by the cultivation of different crops. The nutritional value of food is very important to determine the health status of the people. Therefore, there is a strong relationship between the food and its nutrition content to the people. Moreover, the low nutritional value of food especially with less or no micronutrients is an important issue and cause adverse health issues especially to the people who have no alternative source for nutrient supplement [15]. Therefore, the nanofertilizers could be an alternative approach to add nutritional value to the important staple crops to address the challenges on malnutrition [16].

This article focus on the nanofertilizers and their potential role in the present agriculture system, further, the use of different nanoformulations and underlined mechanism to increase crop productivity, soil fertility, NUE, and enhanced food nutrient values or increased nutritive value etc. moreover, it will lower the synthetics fertilizers requirement and promote environmental sustainability and help toward agricultural sustainability with more yield and better nutrient food quality to deal with malnutrition.

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NANOFERTILIZERS

Nanofertilizers are defined as the materials that are composed of materials exist in the nanoscale level. They are mostly nanoparticles. They carry the important plant nutrients and deliver them to the crop plant in a sustainable and controlled manner [8].

The four important groups of nanofertilizers are classified as (i) Macronutrient nanofertilizers (ii) Micronutrient nanofertilizers (iii) Nanomaterial enhanced fertilizers, (iv) Plant growth-stimulating nanomaterials [13, 17]. Nanofertilizers (NFs) usually take 40-50 days to deliver nutrients, which can synchronize to the pace with plant nutrient uptake ability. While conventional chemical fertilizers quickly made most of the nutrients available to the soil (within 4-10 days) causing loss of nutrients through many ways, including leaching and loss in the environment [18]. Nanomaterials loaded with nutrients increase crop production by increasing nutrients availability in soil and nutrients uptake. Moreover, nanofertilizers also facilitates to boost crop productivity by increasing germination of seed and other plant physiological and metabolic attributes including photosynthesis and protective responses against both biotic as well as abiotic stresses[19].

Further, nano fertilizers based on their development and formulations are classified into three types i.e., Nanoscale fertilizers, nanoscale coating fertilizers and nano-additive fertilizers. [20].

Nanofertilizers can slowly dispense nutrients in optimum quantity to target organelles in plants to facilitate nutrients to plants out of it, in the ecofriendly manner [21]. Nanoscale fertilizers are composed with nutrient nanoparticles, whereas in nanoscale additives fertilizers nutrient nanoparticles are supplemented to traditional fertilizers to increase nutrient uptake in plants. Further fertilizers coated with NPs were classified as nanoscale coating fertilizers. Even the encapsulation of nutrients is also one of the common approaches to produce nano fertilizers [22]. The targeted nutrients are packed (encapsulated) into nanoporous material rendering nutrient to diffuse in a regulated manner, or the nutrients coated with fine polymer film composed of nanomaterial offers another strategy for effective nutrient delivery to plants in a regulated manner. Additionally, the development of improvised nano-formulations further helps prolonged use and regulated delivery of nutrients for effective and balanced uptake by the plant to sustain productivity and also minimize nutrient loss [23, 24].

The macronutrient nanofertilizers are mainly composed of macronutrients (i.e., N, P, K, Mg, and Ca) whereas micronutrient nanofertilizers constitutes micronutrients ie. iron, copper, zinc manganese and molybdenum etc. Micronutrients are required in very trace amount and yet very essential for crop growth in association with macronutrients. The modern agriculture system needs to develop and produce eco-friendly macronutrients formulations, especially nitrogen and phosphate nanofertilizers for sustainable crop production by replacing them with traditional synthetic N fertilizers. The role of nanofertilizers become crucial for regulated nutrients delivery to plants even under adverse and stress full conditions [21].

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It has been observed in several research findings that, the use of micronutrient-containing NPs indicated that they could be a better option to enhance crop yield probably by the better supply of nutrients to the plants. Nanofertilizers may be formulated using different types of nanoparticles alone or in combination, they may consist of zinc oxide nanoparticles (ZnONPs), silica, iron and titanium dioxide, ZnS/ZnCdSe core–shell quantum dots (QDs), InP/ZnS core–shell QDs, Mn/ZnSe QDs, gold nanorods, Al_2O_3, TiO_2, CeO_2, and FeO [25]. Nanofertilizers are mostly studied on metallic nutrients like Cu, Mn, Zn, and Fe. Also, Al, Ce,La, and Ti and oxides of metals ZnO, TiO_2, Fe_3O_4, CeO_2, Au, Ag, Cu, and Fe nanoparticles., were also used as nanoparticles in plants for their positive effect on soil fertility and nutrient enhancement/ fortification in plant [26].

The nutrients that immobilized or encapsulated in nanocarrier are activated and released by three important factors i.e., biological factors, physical factors and chemical factors, which cause the the biodegradation of coating, solubilization of material or pH variation, soils types causes the effective release of nutrient [27].

NUTRIENT USE EFFICIENCY

Several observations and reports consolidate the idea of enhanced nutrient use efficiency in plants. It important if plants are able to utilize the nutrients effectively, the yield is going to be increased even under unfavorable conditions. The nanofertilizer formulations consisted of vital nutrients when applied to crops using any of the several ways to facilitated nutrients resulted into effective nutrient management and improved yield. The high Nutrient uses efficiency (NUE) could be attributed to better nutrient transport and effective delivery through plasmodesmata (nanosized channels) in plants usually 50-60 nm, the carbon nanotubes and silica nanoparticles are attributed to effectively transport and delivering different cargos to the target site in plants. Nanofertilizers have shown high nutrient use efficiency by plant resulting into increased nutrient uptake as plant cell wall have small pore size of up to 20 nm range [28]. Moreover, The extremely porous plant roots at the nanoscale primarily involved to uptake the nutrient from the soil, the process and efficacy of nutritional uptake is depended upon different factors for example plant morphology, growth stage, particle size, availability and exposure time etc. therefore, uptake of nanofertilizers using plant roots system can be enhanced using root exudates, molecular transporter via ionic channels and even creation of new pores or ion channels or even by exploitation of endocytosis process [26].

The development of nanonutrient formulations and their role application in crop nutrient management system and effect on crop yield is a potential approach to enhance crop productivity and reducing quantity of high doses of chemical fertilizers without affecting the crop yield, the increased NUE and improvised uptake of nanofertilizers have certainly boost agricultural productivity [29]. Nanofertilizers have been projected as a most promising and effective technological advancement in contemporary agriculture to cater for the growing need of food demand through controlled crop

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nutrient fertilization and improved nutrient use efficiency. The use of nanofertilizers can raise crop production to 30% as compared to traditional fertilizers [30].

There are various studies revealed that phosphorous and iron are important nutrients belonging to macro and micronutrient category respectively. They are essential for optimum growth and development, therefore, the low availability of such nutrients result in poor plant growth and low productivity. Sega et al 2020 conducted a study on cucumber and maize and revealed improved yield and growth when fertilization was achieved through the application of $FePO_4$ nanoparticles, it provides better NUE and bio availability of both nutrients to crop as compared to their conventional non-nano fertilizer[31].

The application of nanofertilizers in modern agriculture system provides an important strategy for nutritional fertilization of crops with minimum loss. Recently in the study by Miranda-Villagomez et al. 2019, indicated the nano-particles carrying KH_2HPO4 exhibited the increased physiological efficiency of phosphorous in root and shoot leading to higher biomass accumulation and increased instant water use efficiency in rice plants.[32]

Nano-fertilizers in several ways facilitate the effective nutrient uptake by plants to increase nutrient use efficiencies by using the unique properties of nanoparticles. The different nano-fertilizers formulations can be developed either by using a single or a combination of different nutrients at the nanoscale. The nanoparticle can be synthesized by adopting various strategies by applying any of the physical (top-down) and chemical (bottom-up) methods, and the desired nutrients can be used as it is for cationic nutrients (NH_4^+, K^+, Ca^{2+}, Mg^{2+}) and after surface modification for anionic nutrients (NO_3^-, PO_4^{2-}, SO_4^{2-}). Several studies revealed that nano-fertilizers can extend nutrients delivery to the plants even beyond 30 days of their application to the plants, which will provide balanced crop nutrition and also foster improved NUE. Which not only enhance crop growth but also crop yield [33].

It was reported by Yogendra et al 2020, the application of nano nitrogen fertilizers in crops raised the nutrient used efficiency to a significant level in crops and also helped to minimize the resources and save 50% of urea use, therefore the application of Nitrogen Nanofertilizers in agriculture sector for crop fertilization could be an important and novel approach to increase nutrient used efficiency and reducing the dependence on synthetic fertilizers especially nitrogen with lowering the impact on the environment[34].

ENHANCING FOOD NUTRIENT VALUE

In recent years, the scientific community has also started focusing in the direction of increasing the food nutrient value in crops, because the nutrients deficiency in food crops is affecting human health.

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Despite having other methods to augment the food nutritional value like dietary component diversification, application of drugs and other commercial fortification methods, such, methods are not enough and costly as well, therefore, nanofertilizers could offer potential benefits to the fortification of food nutrients in important crops. Moreover, different investigations reports indicating that plant nutrient contents were improved when appropriate nano fertilizers were applied to crops, as nutrients from fertilizers can be easily absorbed by the plant to fortifying the nutrient value of food. Appropriate soil fertilization in agriculture sectors is well accepted practice to fulfil the optimum nutrient need by plants for optimum growth and yield. The nutrients required by the plants are provided by use of suitable fertilizers; therefore, nanofertilizers with plant nutrients could be a potential tool to increase food nutrients value [16]. Agriculture is the principal mean of cater human nourishment, therefore food quality and its nutritional value hold importance to a humans health. So if staple food crops are having a poor or low nutritional value in food that could be an important concern regarding poor health relates issues especially related to malnutrition and also imparts adverse effect on socio-economic conditions [35, 36].

Fakharzadeh et al., 2020, recently studied that the application of nano chelated iron fertilizer increases productivity by 27%. Nano chelated iron fertilizer increased biological yield by 27% and along with a 13% increase in protein content. Moreover, the increased content of nitrogen, phosphorus, iron, potassium, and zinc were reported in white rice. It is clearly showing the capability to bio-fortify crops with vital micronutrients in rice [37]. In the other study, the nano chelated iron fertilizers applied on pistachio trees for nutritional fertilization, reported having enhanced quantity of iron content and calcium concentration along with substantial enhancement of soluble sugar content in pistachio trees [38]. Davarpanha, et al., 2016 reported enhanced nutritional quality and yield of pomegranate (*Punica granatum* cv. Ardestani.) by the application of boron and zinc nano-fertilizers [39]. Dapkekar, et al., 2018, reported having high zinc content and high protein content in wheat grain of durum wheat genotypes by applying the Zn-CNP nano-fertilizer. Moreover, it was suggested the utility of Zn-CNP as a novel nanofertilizer which also increase fertilizer use efficiency. Therefore, the approach of ferti-fortification using Zn-CNP nano-carrier could be and useful tool for other crops also. Further, such reports supported the enhanced yield and also nutritional fortification in various food crops by the application of nanofertilizers [40].

CONCLUSION

Nanotechnology is an emerging technology for precision agriculture, which offers the most potential solutions to enhance crop yield component and plant's nutritional value with minimum resource utilization. Nanotechnology offers technology to support agriculture management system although

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the technology is in the juvenile phase in agriculture. The application of nanofertilizers primarily conserve natural minerals and provide regulated and balanced nutrition to crops through enhanced nutrient uptake augmenting the nutrient use efficiency (NUE). Nanofertilizers also have a greater role in the prevention of nutrient loss, water contamination and negative effect on the environment. The nanofertilizers could be helpful for effective crop fertilization and better nutrient utilization in order to get more yields and high food nutrient value, which can helpful in addressing the issues of malnutrition worldwide. The identification, improvisation and development of suitable nanofertilizers formulations for crop nutrient enhancement come up as an innovative strategy concerning other available technologies. Further, it is also important to explore the extensive information on properties and other attributes the nonmaterial needed to get the maximum benefits. Although the nanotechnology is getting more attention to be applied in the agriculture sector to manage agriculture with more precision to address food security, at the same time, it is very crucial to monitor and evaluate the effects, advantages and adversities of nanomaterials on crops and impact on environmental safety, toxicity and other related issues.

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